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ABSTRACT

The document reviews the literature concerning the training effectiveness of flight simulators and describes an experiment in progress at the University of Illinois' Institute of Aviation which is an initial attempt to develop systematically the relationship between motion cue fidelity and resultant training effectiveness. The literature review discloses a dilemma: while the simulator does constitute a viable basic training aid, differences among pilots trained by various methods become statistically unreliable after pilots have gained a small amount of air experience; faulty control results when a pilot, trained in a simulator supplying highly correlated and accurate motion cues, comes to rely on the cues and attempts to fly an aircraft under instrument-referenced conditions which often produce misleading vestibular indications. The current experiment will produce quantitative data on which a simulator designer or user may base a rational choice of how much fidelity to include in his or her device, rather than allowing the budget to fix the level of realism. The research evidence to date suggests that the highest training effectiveness of a simulator may occur well below the cost levels of very high fidelity motion systems. (Author/AJ)

SIMULATOR MOTION AS A FACTOR IN FLIGHT SIMULATOR TRAINING EFFECTIVENESS

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The exceptional range of fidelity (and cost) of flight training simulators in use would suggest that there is an insufficient level of understanding of the elemental contributions of various cue dimensions to the overall effectiveness of the training device. This lack of complete understanding has usually resulted in selection and procurement of the highest fidelity simulation that the state of the art and budget can provide in an attempt to maximize effectiveness. Related research suggests that this objective may not have been realized in every case -- particularly in a cost effectiveness sense. The one dimension of environmental fidelity which is probably most cost sensitive is that of motion cue structure. It is essential, then, to determine the relationship between motion cue fidelity and resultant training effectiveness in order to optimize the cost efficiency of the training system. An experiment in progress is an initial attempt to systematically develop this relationship for basic flight training applications.

The techniques by which a novice is educated to the skills required for the operation of an aircraft have been refined considerably over the history of flight training. Grahame-White and Harper (1916) describe the process as practiced in England in that time as consisting of a good deal of discussion on the ground between student and experienced aviator prior to the student's attempt to master the vehicle on his own. It is suggested that three of four flights were usually sufficient to prepare the student for his certification flight, which consisted of a series of passes around a closed figure-eight shaped course about two pylons "at least 200 yards apart." Having successfully demonstrated sufficient skill in guiding the aircraft around the course in the presence of an official witness from the British Aeronautical Society (the regulatory agency empowered at that time to certificate applicants for flying licenses), the student was awarded a pilot's license which permitted him, among other things, to instruct others in the secrets of the art of aviating.

Of course, as the vehicles themselves became more complex, the increased demands on the operators required a more comprehensive tutelage, certification process, and the imposition of standards with regard to the experience of and methods employed by flight instructors. The requirements of two great wars for the rapid training of a large number of skilled aviators prompted the pursuit of greater productive efficiency from the flight training process through the development of improved methods and training aids. A natural avenue of investigation in an era when the utilization of each aircraft diverted to flight training activities meant one less aircraft available for combat use was the development of training tools which could shorten the time required to achieve proficiency in the aircraft by substitution of practice in a suitable alternative environment. Efforts toward this end culminated in the late 1930s with Edwin Link's invention of the first widely used flight trainer.

The early flight trainers were little more than mechanical contraptions which grossly responded akin to aircraft to control input from the student pilot. As flight instruments permitting reliable all weather flight came into being, these appeared in the trainers to aid in the development of instrument interpretive skills. Advances in servo-mechanical engineering and electronics brought improvements in the technical ability to replicate aircraft dynamic response. At the end of World War II, according to Smode, Hall and Meyer (1966), simulators and other synthetic devices had come into wide use for initial skill training of student pilots, transition training, refresher training, skill maintenance, and training for specific types of missions. Adams (1961) points out that this employment of a flight training simulator can be rationalized on a number of grounds: economics favor the use of the relatively* inexpensive-to-operate simulator rather than the parent aircraft; the simulator may be used for teaching skills which are too complex, expensive, or risky to practice in the aircraft; the simulator affords a measure of control and the ability to isolate and practice particular segments of the overall flight task, whereas the aircraft does not; the simulator operates independent of prevailing weather conditions; and finally the simulator provides an opportunity to practice the operation of single place aircraft under supervision which would be impossible in the aircraft itself.

Transfer of Training

The measure of the worth of a flight training simulator in a specific training curriculum is established quantitatively by transfer effectiveness. The issue in deciding whether the training system should include a training simulator is the determination of the extent to which time spent in the simulator would reduce the need for training time in the aircraft to reach a stated level of proficiency. If simulator operating cost is less expensive than that of the aircraft by a ratio greater than the transfer ratio, a saving of overall cost may be achieved by employment of the simulator in the training system as evaluated. Transfer is often quantitatively expressed as follows:

$$T = \frac{C - E}{C + E} \times 100\%$$

where

C = trials to criterion in transfer task of control group
E = trials to criterion in transfer task of experimental group

* in the case of highly complex simulators, the operating costs although lower than those of the parent aircraft are none-the-less significant.

If the experimental group takes more time on the criterion task (practice to given standards of performances in the aircraft) than the control group, the numerator is negative, and an inhibiting, or negative, transfer of training is said to have occurred. If the two groups take exactly the same time to reach criterion, the ratio takes on the value of zero, and no transfer is considered to have taken place. On the other hand, if the practice of the experimental group prior to the criterion task does have a beneficial effect in terms of shortening the time to criterion performance, a positive transfer between 0 and 100% will have occurred.

There have been several researches of the transfer of training value of flight training simulators, the almost universal conclusions of which are that there is positive transfer of training associated with practice in a simulator. Many of the often cited examples were conducted at the University of Illinois' Aviation Psychology Laboratory during the late 1940s and early 1950s. For example, Williams and Flexman (1949) demonstrated that non-pilots could be trained to perform a series of maneuvers using a Link trainer and airplane in an alternating practice sequency with 28% fewer trials and 22% fewer errors than a group trained entirely in the aircraft. In a follow-on effort with expanded scope, Flexman, Matheny, and Brown (1950) demonstrated that a simulator used in a properly constructed curriculum could reduce flight hour requirements to achieve private pilot proficiency by more than 50%. More recently, Povenmire and Roscoe (1969) investigated the time savings impact of the use of the Singer Link GAT-1 trainer on the basic flight training curriculum here at the Institute of Aviation. They confirmed that the use of the simulator for practice has positive transfer to a Piper Cherokee 140B aircraft in this application, resulting in a savings of time in the in-flight practice segment of the course. Subsequently (1973), they investigated the relative transfer effect associated with a number of different practice ratios of GAT-1 and aircraft and found that there is a diminishing returns effect associated with time spent in the simulator past a certain point. They developed a measure which reflects this effect, incremental transfer effectiveness – the time saved in flight by each additional hour spent in the simulator. It was demonstrated that if the relative costs of training in the simulator and aircraft are known, it is possible to design a curriculum which minimizes total cost by selection of a most cost effective period of practice in the GAT-1. Other studies have examined the respective proficiency levels of groups trained in combined aircraft/ground-trainer and aircraft-only curricula (Mahler and Bennett, 1950; Wilcoxon, Davy, and Webster, 1954; etc.) with findings that the simulator trained groups were as or more proficient than aircraft trained groups with equivalent or less aircraft time.

It will be stipulated then, in view of this evidence, that the simulator does constitute a viable basic training aid, and that this is a widespread belief is evidenced by the fact that such devices are in common use throughout the basic flight education field. The beneficial transfer effects demonstrated in the cited studies apparently are sufficiently valuable to justify the outlay of the funds for procurement of training simulators by even the smaller of the flight training institutions, although the competitive pressures of this industry no doubt also had some influence here as well. These transfer effects are not, however, uniform across the entire spectrum of skill categories which together comprise the requirements for pilot certification. Ornstein, Nichols and Flexman (1954) analyzed the transfer effects of the use of a simulator in conjunction with aircraft as compared with the aircraft alone on a maneuver by maneuver basis to find that the simulator was most effective for certain classes of procedure loaded contact flight exercises, and least effective on maneuvers which the simulator did not well reproduce. They discuss the relationship between the transfer effectiveness of the simulator and the fidelity of simulator reproduction of the aircraft procedural and environmental cue structure, suggesting that by extending the range and fidelity of the simulation, transfer is maximized. This would logically follow by analogy from the Osgood Transfer Surface (Osgood, 1949) concept which hypothesized heightened transfer as a result of similarity between the practice and criterion tasks in the general transfer situation as opposed to the flight training context.

Fidelity and Transfer

This question of the relationship between the fidelity or realism of the simulator as compared with its aircraft counterpart as a determinant of transfer of training value became more important to the designers and purchasers of simulator systems as the state of technology advanced to make possible high fidelity simulation but only at a very great increase in simulator cost. Investigators began to examine the relationship between transfer value and realism along a number of simulator design dimensions. A basic and related investigative issue is the question of whether a simulator is really required, or whether an environment conducive to mental and physical practice of procedures without feedback might do as well. Dougherty, Houston, and Nicklas (1957) examined the training effectiveness of four alternative ground training devices including an operational flight trainer, a procedures trainer (without dynamic instruments), a photographic mockup, and the procedures trainer with an auxiliary side tracking task. These represent four levels of physical fidelity to the object aircraft. Each group was assigned one of these training aids for a program of procedures and maneuvers. Each then transferred to the aircraft and was compared in the airborne training program with a fifth group trained only in the aircraft.

All trainer groups performed significantly better on the first air trial than did the aircraft only group, but by the third air trial, the differences were not statistically reliable. The groups trained in the simulator and procedures trainer showed the highest degree of transfer, but again by the third air trial, no differences could be observed as a function of training method. The conclusion reached of importance here was that in addition to demonstrating that a ground trained group with either simulator or procedures trainer experience could be competitive with an entirely air trained group, the transfer of training could not be shown to be sensitive to the degree of physical and task fidelity in the trainer. Matheny, Williams, Dougherty, and Hasler (1953) had already demonstrated that faithful reproduction of flight control feel was not an essential characteristic of the flight trainer for reasonably high transfer to occur, and such studies in other training areas as that by Briggs, Fitts, and Bahrick (1956) demonstrated that control feel was not closely related to transfer of training for a generalized tracking task tend to contradict Osgood's notions (1949) about this similarity being critical for efficient transfer to take place.

Motion Cues and Simulator Fidelity.

The accuracy of reproduction of the cue structure of an aircraft in flight as provided in flight training simulators has been greatly improved since the early attempts at synthetically generating these cues. Instrument indications and control pressures can be virtually identical to those of the object aircraft if sufficient resources are allocated to the computation of aircraft dynamic response and if sufficiently accurate models are employed. Real time, computer generated visual systems have enabled the simulator to provide a highly realistic analog of external visual cues, provided the customer can pay for these cues as well. Motion systems have also been developed which do an excellent job of generating acceleration and rotational cues to the simulator pilot which closely approximate those which may be measured in a real aircraft -- except for those cues of linear and rotational acceleration associated with rolling into, out of, and the maintenance of turns.

This cues fidelity problem will be easily understood by consideration of the physics of an aircraft in turning flight. When turning, the aircraft, in addition to being acted upon by the normal forces of flight; lift, drag, thrust, and gravity or weight, comes under the influence of a fifth acceleration force -- centripetal acceleration. The pilot within the aircraft is acted upon by this force as well. His vestibular system is incapable of differentiating between the component accelerations together composing the total motion cue environment, however, and he feels only the vector sum of all of the accelerations acting upon him. Thus in the aircraft, in a steady state turn, gravity and centripetal accelerations are perceptually combined to produce a resultant vector, which in a properly coordinated turn acts perpendicular to the plane of the wings.

The sensation for the pilot is one of increased weight alone, not one of turning or sliding across his seat. In a properly coordinated turn, the magnitude of this resultant vector, and hence his perception of weightiness is parabolically related to the angle of bank and consequently the rate of turn. In the simulator, however, only the force of gravity acts on the pilot unless the simulator cockpit is able to generate centripetal forces as, for example, in the case of a cockpit on the arm of a centrifuge. This will not be the case in most instances; the centripetal component of the acceleration environment will be missing. Where a centrifuge is used to generate the cues, the short radius of turn, as compared with the turn radius of an aircraft, produces other anomalies which detract from the realism of the motion cue set as well. The simulator thus will not reproduce accurately turning cues representative of an aircraft.

An approximation commonly used is the so called washout motion approach, in which the roll accelerations of the simulator cab are analogous to the roll accelerations of the aircraft, with exponential decay back to earth level at such a slow rate that a sustained turn is represented to the pilot by a level cockpit although he is not aware of the transition back from the banked condition. This is a compromise, however, and even though the direction of the resultant vector during a turn is appropriate with the washout motion, the magnitude is less than it realistically should be.

Even with this limitation, motion cues in the simulator do become a part of the total informational environment available to the simulator pilot. The processing of this information and the way that it is used to assist in the control of the vehicle may differ, however, from that adopted in the aircraft. If we consider the generalized vehicle control problem, we have a classical man-in-the-loop control system. The man is presented with various informational cues from his environment through his various senses. These cues are received, transformed, combined, processed and then used as imputs to a control model; we might term it an operative model; in order to determine what the state of the control process is, and what must be done to make the system conform to the desired state.

Motion cues have been hypothesized as playing two parts in the operative model of an aircraft. They may certainly be used as quantitative inputs to the control model to assist in the real time computation of appropriate control movements. They also may serve in an entirely independent fashion as a generalized alerting cue which signals the need for control action but is not used in the determination of what control action might be required. Flexman (1966) discusses a study which suggests that for the experienced pilot, the latter was the case. Student pilots trained to make instrument takeoffs in a motionless simulator performed with much greater success than did a group of experienced instructor pilots who it seems had grown to depend on motion cues as a signal that the aircraft attitude was changing. Even though these same instructors know full well that a continuous mechanical scan of the instrument panel is necessary to maintain control of an aircraft by instrument reference, and that in a real airplane vestibular cues are not reliable information sources in the absence of external visual confirmation of vestibular impressions, they apparently had come to depend upon vestibular cues as a signal to scan the instrument panel to discover the source and nature of the attitude change underway. Students trained in the motionless simulator had become much more dependent upon the mechanical scan, and did not so rely on vestibular alerting cues. They were, therefore, able to maintain control in the absence of them.

There are a few studies which compare pilot performance in motion equipped and motionless simulators and both of these with performance in an aircraft, (Douvillier et al., 1959; Rolfe, et al., 1966; Fedderson, 1961). In general it has been found that performance in a simulator with motion more closely approximates performance in an aircraft than does that observed in the fixed base simulator. Transfer of training comparisons, however, fail to support the notion that motion is an important contributor to increased transfer value. In the Fedderson study for example, although the motion trained students showed greater transfer to an aircraft on the initial aircraft trial, reliable differences had disappeared by the sixth transfer trial. Fedderson concludes that the use of a motion simulator was difficult to justify in view of this. Smode et al. (1966) review a series of

NASA studies examining the requirement for motion in simulators where the task was aircraft control for experienced pilots, and in this extra-training context, they summarize the findings as justifying motion only in the case of simulation of an aircraft where the motion cues present an essential stability contribution (for example, in the case of anticipatory cues), or where realistic motion is an inhibitory factor such as might be the case in vehicles with unusual dynamics or high vibration levels. Caro and Isley (1966) evaluted a tethered helicopter as a trainer for basic helicopter students and found that while those students who received the training performed better up to the first-solo flight, all differences disappeared after this point and the conclusion was reached that the value of motion simulation of high fidelity is of limited value for long-term transfer purposes.

In each of the foregoing examples, performance differences were observed between groups of students trained on high fidelity motion devices and those trained on motionless simulators which initially suggest that the motion-trained students learn to achieve higher performance more quickly. However, an important distinction needs to be made; the function of the motion cues as learning vs. action feedback in the control task. Holding (1965) discusses the role of feedback in the learning process. He reviews a large number of studies in proceeding to the conclusion that the intrinsic, concurrent, and immediate nature of such performance cues as motion feedback of control inputs is more promotive of high performance than of rapid learning. It would seem that motion-trained students are presented with a practice environment which is richly endowed with aiding cues facilitating performance of the practice task at very high levels relative to that provided the no-motion student.

Koonce (1974) conducted a study which supports this contention. Koonce was attempting to validate the use of a ground-based simulator as a proficiency evaluation environment by comparing performance in the simulator with performance in an aircraft. He found that those pilots presented with the more difficult task of performing the check ride maneuvers in the motionless simulator performed less well in the simulator than those tested with motion, but that this difference was radically reversed in the aircraft (see Figure 1). The difficulty of the task for the motionless simulator group apparently served to strengthen skills required for superior aircraft performance to the detriment of simulator performance. The criterion in this instance is aircraft performance level however. It seems clear that if any skill increase was taking place, as the negative slope in Figure 1 would suggest, the difficult task, without motion, was a better learning environment than the easier motion case.

Let us consider the notion of an operative model once again. If we accept the previously discussed general concept of the man-machine control loop as being a useful model for discussion, we may state that it is the task of the student in basic training in any skill to derive empirically an operative model by associative experimentation with input information and trial and error control outputs. Of course this process is speeded by the presence of an instructor, but the student must experiment

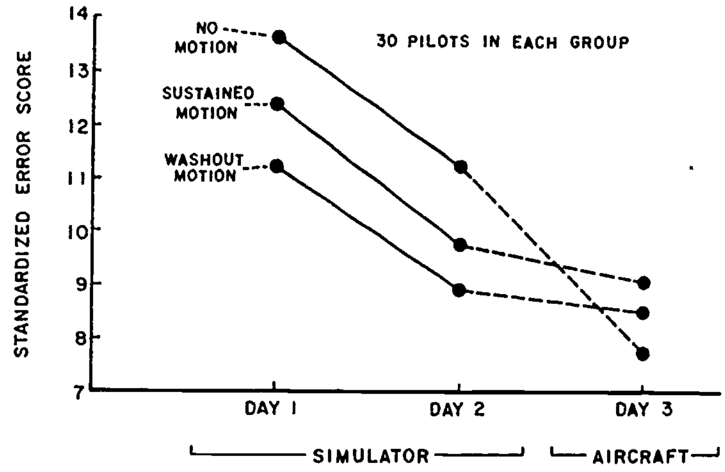

Figure 1. Performance in an instrument flight skill evaluation under three conditions of simulator motion (Koonce, 1974).

with the quantitative aspects of control response even if the qualitative aspects are provided by instruction. He must learn how hard to push the stick forward to break a stall, how soon to anticipate the flare point by pulling the stick back and with how much force, even if he knows qualitatively beforehand that these are appropriate actions. It is only reasonable to assume that in the formation of an operative model, the student will utilize all of the relevant and correlated informational cues available to him to make the task as easy as possible.

Thus if a student is trained in a simulator which provides a cue structure that is more abundant than that provided by the aircraft, the student will include these extra cues in his operative model, and when removed, the lack of these cues will require adaptation to maintain performance levels. What will happen, however, if the student believes that all the cues required for the operative model are present when in fact they are not, or are in fact present but false. Faulty control must result.

This is precisely the situation which will arise when a student pilot is trained in a simulator which supplies highly correlated and accurate motion cues, comes to depend upon them, and then attempts to fly an aircraft under instrument referenced conditions which often produce misleading vestibular indications. Would it not have been better for this particular student to have been trained under a condition of no motion cues at all, so that his operative model makes no use of these misleading cues? Perhaps, but what if he is incapable of ignoring them entirely? There is no point at which we can say that learning has ceased and performance has begun. Thus it is possible that the operative model will be continuously modified to take advantage of cues available. Is this process of adding to the complexity of the model more inhibiting than revising it to exclude previously available terms? This is a dilemma which has yet to be explored fully.

What Is Being Done?

A survey of the simulation devices in common use for basic flight training will confirm the impression that the manufacturers and buyers of this class of device have very little idea of the component contributions to transfer effectiveness of the various dimensions of cue fidelity. With respect to motion cue fidelity, it is possible to procure systems which provide either no, poor, or quite good but imperfect roll motion simulation at prices which correspond to the fidelity offered. If roll motion fidelity is an important determinant of transfer, the purchasers of the no-motion systems may not be getting an appropriate return on their investment. If not, as some of the earlier cited research seems to indicate, money spent on motion systems is wasted. The question of how much roll motion fidelity is required to produce cost effective transfer has not been satisfactorily answered.

The fidelity of roll motion is not a single dimension of measurement, but rather a multidimensional variable itself. In addition to the very basic question of whether there need be any roll motion at all, the character of the motion cues may be just as important an issue. In part, the answer will rest upon the use to which the cue is put in the operative model. If the roll motion cue serves only an alerting function, then any perceivable intensity of stimulation in any direction should serve as well for a naive interpreter. If, however, the magnitude, temporal character, and direction of the cue are also important, motion cues which are then uncorrelated with attitude state in any of these dimensions could not be used to produce useful corrective control inputs by way of the operative model process. The experienced flight instructor will caution the student to ignore motion cue direction and magnitude because in the aircraft these can be misleading, even though as Flexman (1966) found, the instructor apparently will not or cannot ignore them himself.

It becomes important then in addition to examining the impact of the motion cue structure on transfer, to distinguish whether these cues are being used by the naive trainee as alerting or informational signals. At the Aviation Research Laboratory of the University of Illinois' Institute of Aviation, a study is in progress intended to disclose the function and significance of motion cues in the simulator. We are running a classical transfer experiment involving four groups of flight naive subjects. One group serves as a control and is being trained to perform a series of basic instrument referenced maneuvers in a Piper PA-28R-200 Arrow single engine light aircraft. The other three groups receive preliminary instruction in a Singer Link GAT-2 training simulator prior to beginning the instructional sequence in the aircraft. These groups receive their simulator training under three motion conditions; none, high fidelity washout motion, and directionally uncorrelated random-roll washout motion respectively.

If it is found that the third and fourth groups have equivalent transfer performance, it will be apparent that the directionally random washout motion which can serve only as a general alerting signal is as effective in facilitating aircraft control as is correlated, highly realistic motion. If, however, the higher fidelity motion provides reliably greater transfer, it will be apparent that the direction and magnitude of the cues have a purpose in the operative model as well. If the no-motion group transfers as well as the two motion groups, the value of motion cues of either variety as an adjunct to transfer will be questionable. The aircraft only group will serve as a standard for judgment of the value of simulator practice as abstracted from the motion cue structure.

The Training Task

If differences between these groups do in fact occur, they will be amplified by operating at the early, steep portion of the learning curve. Naive subjects are being taught the most basic elements leading to the first major milestone in pilot training, the solo flight. Exercises representative of this early training are taught on a trial basis, with total trials to reach criterion performance and total errors to reach criterion performance serving as the measures for analysis. These elements include procedures and techniques for climbs, glides, straight and level flight, turns, and basic instrument referenced flight.

A recording and scoring system used by Williams and Flexman (1949) is used. The technique calls for the instructor to judge whether each trial on a maneuver met stated standards of performance along critical dimensions. If a predetermined number of successful attempts are made by the student, the instruction advances to the next phase. Failure to meet criteria requires repeat of the trial.

Subjects

Subjects are volunteers who have no previous piloting experience. Since aptitude for flight training is a measure which exhibits considerable individual variation, two means were used to balance experimental groups. First, a sufficiently large sample will be made to minimize the effect of these differences. Twelve students will be assigned to each of the four groups, making a total of 48 subjects for the experiment. Second, each of the potential subjects has been tested with a battery of flight training aptitude measures, and groups will be balanced across these. The aptitude tests will include a divided-attention time-sharing performance task involving simultaneous tracking and number processing, a mental arithmetic test, and the Guilford-Zimmerman Pt. V Spatial Aptitude test. Seven measures resulting from these tests are used to assign students to groups. A discriminant analysis of the subject population scores has shown that the groups are properly matched with respect to each of the seven measures.

Instructional Technique

Several flight instructors are involved in the experimental training program. To minimize the effect of instructor variation, material is presented to the students largely in the form of audio and video tape cassettes with a minimum of real-time interaction between student and instructor. The instructors function principally as maneuver scorers and safety pilots.

Skill Areas Sampled

Fitts (1962) considered the skill content of such perceptual-motor processes as aircraft control and concluded that there are three principle constituent activities; spatial-temporal patterning, continuous interaction of response processes with input and feedback processes, and learning. While learning will pervade the other processes in this program, measures and maneuvers have been selected which will sample the development of each of the first two activities. Maneuvers included in the curriculum will draw on (1) basic motor control and the development of a "feel" for the airplane as indicated by skill with the primary controls and the trim tab, (2) perceptual skills as indicated by instrument referenced flight performance, and (3) supporting mental and imaginational skills as revealed by instrument referenced orientation and navigation.

Analysis

An analysis of variance based upon total trials to criterion performance will be used to compare performance by treatment group to examine the transfer effects of the various motion conditions. In addition, a past hoc examination of the predictive validity of each of the seven balancing measures against total trials to criterion across skill areas will be made to examine the effectiveness of the group matching measures. Correlations of matching measure scores with individual maneuver scores will further amplify the predictive value and limitations of these measures.

Results

At the conclusion of the effort, it will be possible to state with greater certainty how the gross characteristics of flight trainer roll motion cues relate to the transfer of training effectiveness of the device when applied in a basic training program. Although this is only a first step in the total process of delimiting the total contribution of specific motion cue characteristics to the training value of the simulator, the course for future research will be more clear. If it can be shown that the transfer of training value of the simulator is in fact relatively insensitive to the presence or absence of these cues, or to the fidelity of their reproduction where present, the implications for flight training will be very significant. With quantitative data available as to the degree of transfer which may be expected from simulators with varying characteristics, the simulator designer or user may for the first time make the choice of how much fidelity to include in his device on a rational basis. The prevailing custom of letting the budget fix the level of realism in the simulator will be supplanted by systematic maximization of the transfer effectiveness within the constraint of cost. The research evidence to date suggests that this maximization when determined in a cost effectiveness framework may occur well below the cost levels associated with very high fidelity motion systems.

A very realistic possibility is that the characteristics desirable in the motion system of the simulator will be found to vary as a function of the training objectives it will be expected to meet. We have earlier seen that a given simulator will produce differential transfer across a maneuver set with differing skill components. It is anticipated that this study will reveal that the provision of high fidelity roll motion simulation may facilitate the learning of simple motor control and tracking to some extent, but if Koonce's (1974) findings are generalizable to the instrument referenced flight situation, high fidelity may hinder learning as compared with no motion or directionally random motion conditions. With respect to the development of the imaginational components of piloting skill, it is difficult to predict whether motion characteristics will have any transfer implications beyond those associated with heightened realism and possibly resultant increased motivation of the student.

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